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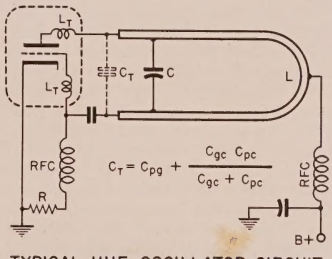
UHF Receiving Tubes and Circuits

By the Engineering Department, Aerovox Corporation

IN the past, commercial use of the ultra-high frequency portion of the radio spectrum (300-3000 Mc.) has been somewhat limited. Now, with the recent allocation of the 475-890 Mc. band for UHF television, and the inauguration of the Citizens Radio Service in the frequencies between 460 and 470 Mc., it is certain that this region will become increasingly active.

Since the vacuum tubes and associated circuitry employed at such frequencies, it should be valuable to review them at this time. This study will be confined to triode tubes of the conventional negative-grid type which are most likely to be utilized in receiving circuits for UHF television, Citizens Radio, and UHF amature communication. Specialized microwave tubes, such as the klystron and the magnetron, will be the subject of future AEROVOX RESEARCH WORKER articles.

In UHF receivers of the superheterodyne type, it is usual that only the "front-end" tubes, i.e., the r.f. amplifier, mixer, and local oscillator, are of special high frequency design. The other tubes and circuits beyond the mixer are usually of the low frequency variety. Similarly, in the superregenerative receiver only the detector and r.f. stage (if used) function at the carrier frequency. Actually, above 500 megacycles there are very few effective r.f. amplifiers available in the low cost field, and the function of mixing, or frequency conversion, is being widely assumed



TYPICAL UHF OSCILLATOR CIRCUIT
FIG. 1

by the silicon crystal diode, since in this range it exhibits better noise performance than the vacuum tube as a mixer. Therefore, at the present time, tubes for local oscillator or superregenerative detector service are of primar y interest as being the remaining tubes which must operate near the frequency of the UHF signal to be received in most designs.

Factors Limiting High Frequency Performance

Receiving tubes of conventional design are not capable of satisfactory performance at ultra-high frequency because of several limitations which are inherent in their construction. Chief among these limiting factors is excessive interelectrode capacitance and inductance. That these quantities set a definite upper limit on the frequency of operation of a given vacuum tube design may be seen by considering the typical UHF oscillator circuit of Fig. 1. In this circuit the frequency of oscillation is determined by the values of resonant circuit inductance (L) and capacitance (C) as related by Thomson's formula:

$$(1) \qquad f = \frac{1000}{2\pi\sqrt{LC}}$$

Where: f is the frequency of oscillation in megacycles.
L is the circuit inductance in microhenries.
C is the circuit capacitance in micromicrofarads.

From this equasion it is seen that the frequency of the resonant circuit varies inversely as the square root of the product LC. For operation at frequencies above 300 megacycles, this product must be less than .28. However, as shown in Fig. 1, the inductance of the leads within the tube and the capacitance between the electrodes must be added to those of the external circuit. Thus, if an attempt is made to use a conventional

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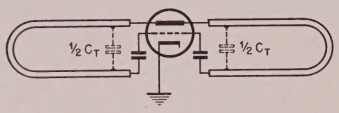


R.F. CIRCUIT
OF DOUBLE-ENDED OSCILLATOR
FIG. 2

receiving tube (such as a 6J5) at such frequencies, it will be found that the product of the capacitance of several micromicrofarads contributed by the tube and the inductance of the small wire leads which connect the elements to the base pins would be considerably greater than .28, even with the external circuit reduced to a direct connection between the grid and plate. Operation under this condition is sometimes called the "self-resonance" of the tube in manufacturers data sheets, but does not represent a practical operating point since the efficiency of such a circuit would be very low, coupling would be difficult, and tuning nearly impossible.

Another factor which prevents the efficient operation of common receiving tubes at the ultra-high frequencies is "transit time", or time required for an electron emitted from the cathode of the tube to reach the anode. For practical operation, this "time of flight" must be a small fraction of the period of one r.f. cycle — usually less than one-tenth. If it is appreciably longer, the output of the tube becomes small. This decrease in efficiency results from the fact that long transit time prevents the electrons from remaining in the proper phase to deliver maximum energy to the oscillating circuit. In other words, with excessive transit time, the r.f. field between the tube electrodes may reverse while electrons are traversing these spaces, so that the electrons absorb energy rather than deliver it.

Excessive circuit losses also limit the use of standard receiving tubes to the lower frequencies. Such losses may take several forms, including:

(a) *"Skin-effect" losses.* Since ultra-high frequency currents flow mainly on the surface of metallic conductors, the resistance of the small wire leads usually used in tubes is very much greater at these frequencies than at lower frequency.

(b) *Circuit radiation losses.* At UHF wavelengths, even a short length of wire may radiate considerable energy. Tube leads, unless spaced close to others carrying out-of-phase currents, will cause r.f. radiation losses which reduce efficiency and output.

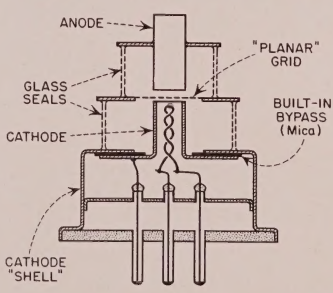
(c) *Dielectric losses.* The standard bakelite bases and glass "presses" used in most receiving tubes are too lossy for use at UHF. Such poor dielectrics, especially if they occur where electrostatic fields are strong, absorb r.f. energy which is converted to heat. The process is cumulative, since the dielectric losses increase with temperature.

The combined result of the foregoing effects is to cause the efficiency and power output of conventional receiving tubes to drop to impractical values at frequency limits below 100 Mc. for most designs. Even many tubes in the miniature and sub-miniature classes are limited to frequencies below 300 Mc. by these same effects, unless special precautions have been taken in their design.

Special UHF Designs

Table I lists some of the readily available tubes which are effective in at least the lower portion of the UHF band currently of interest. In these tubes, the limitations discussed above have been reduced by special design features. We will now discuss these features.

Transit time may be reduced in a vacuum tube by decreasing the spacing between the elements or increasing the plate voltage so that the electrons move faster. The former is the best approach in receiving tubes, however, since plate voltage must be *quadrupled* to *double* the velocity of the electrons. Thus, rather high voltages would be required to achieve UHF operation. It is usually more convenient to reduce the electrode spacing. This, of course, has mechanical limitations, since the grid-to-plate spacing if the tube is to have a sufficiently high amplification factor (mu.) In most UHF triodes, the grid-cathode spacing is only a few



SHOWING CONSTRUCTION
OF "LIGHTHOUSE" TRIODE
FIG. 3

TABLE I

TYPE	MAX. FREQ. MC.	DESIGN
958A	500	Acorn (Single-ended)
6N4	500	Miniature
955	700	Acorn (Single-ended)
316A	700	Door-knob (Single-ended)
6F4	1200	Acorn (Double-ended)
368A	1700	Door-knob (Double-ended)
2C40	3000+	Lighthouse

thousandths of an inch for these reasons, and is less than .001 inch for one special triode tube.

It will be readily seen that the reduction of element spacings in the vacuum tube to reduce electron transit time has an adverse effect upon the inter-electrode capacitance. As the elements are moved closer together, the capacitances between them increase proportionately. This, of course, reduces the maximum frequency of operation as shown by Eq. 1. The only recourse which the tube designer has in this case is to reduce the area of the tube electrodes to keep the tube capacitances within usable limits. This necessity, in turn, limits the power handling capabilities of the tube by reducing the anode heat dissipation and cathode area. Such considerations explain why the generation of radio frequency power becomes increasingly difficult as the operating frequency is raised.

Tubes of the "acorn" type (955) and the "door-knob" type (316A) represent about the best that can be done by the simple expedient of reducing tube dimensions to minimize transit time, lead inductance, inter-electrode capacitance and dielectric losses. Such tubes function up to about 700 megacycles as stable oscillators. Beyond this frequency limit, tubes which are adaptable to special circuits must be used.

A considerable increase in the upper frequency limit is achieved by the "double-ended" circuit shown in Fig. 2. In this arrangement, the tube is provided with dual grid and plate leads and a separate resonant circuit is connected to each pair of leads. The tube capacitance is now part of two resonant circuits and may be thought of as being shared between them. Therefore, each resonant circuit has only half of the effective capacitance value that the same tube would add in the circuit of Fig 1. For this reason, the size of each of the inductances in Fig. 2 would be considerably larger for operation at

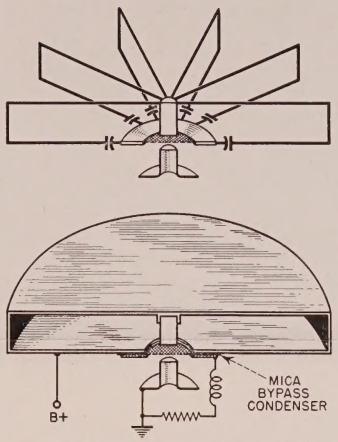
the same frequency, or would permit operation at considerably higher frequency before becoming impractically small. Another way of considering this extension of frequency limit is by noting that the two inductances are now in parallel, which reduces the effective value which resonates with the tube capacitance to approximately one-half. This lower value of inductance, when substituted in Eq. 1, gives a much higher frequency. Another advantage to the use of the double-ended circuit results from the fact that the oscillating r.f. currents divide equally between the two circuits so that skin-effect losses are considerably smaller.

The 6F4 and the 368A are examples of tubes having double-ended construction. The 6F4 is a triode of the "acorn" type with dual grid and plate leads which is especially well adapted to local oscillator service in the UHF television band. It has an upper frequency limit of about 1200 Mc. The 368A is a larger tube of the "door-knob" type, operable to 1700 megacycles.

During World War II, a substantial advance in the high frequency performance of conventional triode tubes was made by the introduction of the planar-grid "lighthouse" tube. The general construction of this tube family is illustrated in Fig. 3. Tubes of this type, such as the 2C 40, serve as grounded-grid amplifiers and oscillators at frequencies exceeding 3000 megacycles.

The improved performance of the lighthouse tube is due to the novel construction employed. The use of "disc-seals" and planar (or flat) cathode, grid, and plate elements permit the factors which usually limit triodes to be reduced to a minimum. This feature was made possible by the development of special metal-to-glass sealing techniques. Lead inductance is extremely low because wire leads connecting the tube electrodes to the external circuit have been replaced by flat metal discs which extend radially from the tube elements through the glass seal. Interelectrode capacitances are very low because the effective heat dissipation of the disc-seals makes the use of small plate and grid areas practical. A good example of the increase in electrode cooling by thermal conduction through the disc-seals is readily seen in the comparison of the rated maximum plate dissipation of the radiation cooled 955 and the conduction cooled 2C40. Although the 955 has a larger active plate area, it is rated at only 1.6 watts dissipation, whereas the 2C40 plate will dissipate over 6.5 watts because of heat conduction through the seal to the external circuit. Losses due to "skin-effect" are also minimized in the lighthouse type of construction since the surfaces connecting the tube electrodes to the external circuit are large and are silver plated, for better r.f. current conduction.

The lighthouse tube, or so-called megatron, was especially designed for use in coaxial or cavity circuits. It may be used in lumped-constant and parallel-line circuits at the lower UHF frequencies, but in such applications its full capabilities are being wasted. The advantages of the disc-seal construction, enumerated above, are only realized in cavity or coaxial circuitry which makes intimate electrical and thermal contact with the entire outer edge of the disc-seals. The evolution of a simple cavity oscillator circuit from the single and double-ended circuits of Figs. 1 and 2 is shown in Fig. 4. Thus, the cavity circuit may be thought of as a "multiple-ended" circuit in which the number of resonant circuits connected in parallel is made infinite so as to form a solid wall completely enclosing the r.f. fields. In such circuits the losses due to radiation are very small. A special by-pass condensor is built into the base of the tube to block d.c. bias voltages but connect the cathode "shell" to the cathode for r.f.



DEVELOPMENT OF "LIGHTHOUSE" TUBE CAVITY OSCILLATOR FROM "MULTIPLE-ENDED" CIRCUIT

FIG. 4

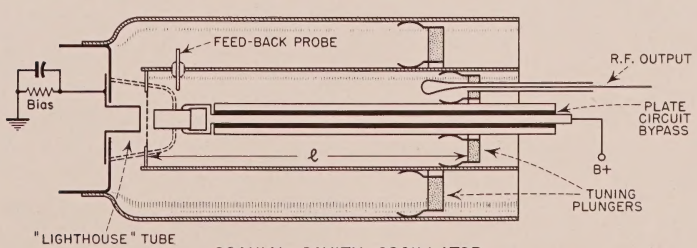
A more practical circuit of the coaxial type is illustrated in Fig. 5. This arrangement uses two resonant coaxial circuits; one connected between the grid and cathode, and the other between grid and plate. The circuit is therefore analogous to the tuned-plate, tuned-grid circuit. Because the grid is at r.f. ground, and forms as effective electrostatic shield between the input and output circuits, the circuit will not function as a self-excited oscillator unless feed-back is intentionally introduced by coupling between the two cavities. Without provisions for r.f. feedback, the circuit functions as an effective grounded-grid amplifier. Tuning is accomplished in coaxial circuits by means of movable shorting "plungers" which vary the length of the coaxial resonator, and hence the resonant frequency, which is related to the length of the resonator by the expression:

$$(2) \qquad \frac{1}{\omega C_0} = Z_0 \tan \frac{2\pi \ell}{\lambda}$$

Where:

C_0 is the tube capacitance shortening line.
ω is 6.28 times the operating frequency.
Z_0 is the surge impedance of line.
ℓ is the length of the line.
λ is the wavelength.
2π is 360 degrees.

This equasion may also be used to determine the approximate length of the parallel line resonant circuits used with single-ended and double-ended oscillator circuits. In the latter case, it must be remembered that only one-half of the lumped capacitance contributed by the tube is used in Eq. 2.



COAXIAL CAVITY OSCILLATOR

FIG. 5

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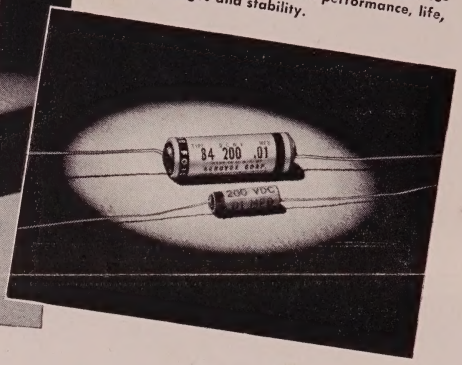

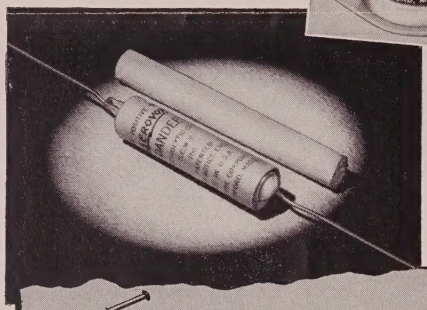

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